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FILE SIZE DETERMINATION FOR WASTE OIL COLLECTION IN THE PROVINCE OF ANTWERP

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Abstract. A mathematical model is presented to determine the fleet size required to collect waste oil in a region. The model consists of (1) a demand model, estimating the amount of waste oil to be collected and (2) a collection model, estimating the number of route per year to the communities within the region and time required to travel to the waste oil producers, to fill and to empty the truck.

Key words: Fleet size, demand, waste oil.

1. INTRODUCTION

1.0. JUSTIFICATION OF THE SUBJECT

The motive to choose this topic originates from a remark in OVAM's (Public Waste Office in Flanders) "waste–plan", stressing that much more operations research had to be done on the waste oil problem.

After examining the waste oil problem a little closer, we decided to study the collection process. We restricted our study to the Province of Antwerp because all required data were not available in other provinces.

1.1. INTRODUCTION INTO THE WASTE OIL PROBLEM

1.1.1. DEFINITION OF WASTE OIL

What is meant by waste oil in this paper is oil from one of the following categories:

- Mineral or synthetic oil or greases.

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- Oily tank residuals or oil sludge.
- Emulsions.
- Waste oil from ships.

The exact definition can be found in the EEC directive 75/439.

1.1.2. LEGISLATION IN FLANDERS

The law forbids to dump waste oil. Industrial waste oil producers should, or get a licence to work up the waste oil, or have it collected by an approved collector. Private waste oil producers can carry their waste car oil to garages or container parks (Vlaamse Executieve,1981).

1.1.3. THE COLLECTION OF WASTE OIL

An approved collector for a certain area is obliged to collect oil when the producer's amount exceeds 200 litres. In reality however collectors are not always willing to do this due to the fact that prices have decreased in recent years (Breton,1984). Moreover the legislation is easily avoidable just by asking high prices to the client.

At present many collectors operate in a very unorganized way. Low oil prices and severe measures against certain collectors have already diminished the number of cowboys, who call themselves "defenders of nature".

There has been a waste oil circuit between Belgium, The Netherlands and Germany in which collectors mixed reasonably good waste oil with very poisonous products. By doing so they avoided that the mix had to be treated as "chemical waste" requiring much more careful destruction than waste oil.

1.1.4. WHAT QUANTITIES ARE WE TALKING ABOUT IN FLANDERS

ESTIMATES:

- Mineral or synthetic oil or greases: 45.457 tons/year
- Oily tank residuals or oily sludges: 69.000 tons/year
- Emulsions: 16.957 tons/year
- Waste oil from ships: 9.720 tons/year

The estimation for the garage or private oil is 29.940 tons/year in Flanders.

The total reported quantity of waste oil to OVAM is:

6.936 tons/year.

It is very difficult to estimate the real quantity of waste oil in Flanders, but we have reason to believe that it is much higher then the reported quantity.

1.1.5. BACKGROUND INFORMATION FOR THE CASE STUDY

At this moment there are 9 collectors in the Province of Antwerp. We only defined three of them in the study; two in the city of Antwerp and one in Westerlo. The 6 other collectors are working in the Antwerp harbor and we did not have specific harbor data on waste oil.

2. MODEL DESCRIPTION

The model constructed mainly exists of two parts: (1) the supply of waste oil per community, (2) the collection process. From both models we give the assumptions made, a description of the data involved and a mathematical formulation of the model.

Using these models the required fleet size can be determined.

In the model descriptions the following notations are used:

I	set of waste oil producers
I_g	set of garages
I_n	set of non-garage waste oil producers
$V^{(j)}$	weight of waste oil of community j
v_i	weight of waste oil of producer i
$n_g^{(j)}$	number of garages in community j
$V_g^{(j)}$	weight of garage waste oil of community j
$V_n^{(j)}$	weight of non-garage waste oil of community j
$v^{(j)}$	average weight per garage in community j
$n_w^{(j)}$	number of cars in community j
V_{gk}	weight of garage waste oil from cars of type k

T	set of type of cars		
$T = c, t, a, f, s$			
where	c	stands for	cars
	t		trucks
	a		autocars
	f		farm tractor
	s		special cars

d_k	average distance made by a car of type k (in kms)
r_{kl}	average distance made during two oil renewals of car of type k of make l (in kms)
o_{kl}	average weight of oil produced in an oil renewal of a car of make l (in tons)
n_{kl}	number of cars of type k and make l
L_k	set of makes of cars of type k
T_{cp}	yearly collection time for the whole province (in hours)
T_{cj}	yearly collection time for community j (in hours)
$R^{(j)}$	number of routes to community j
T_{rj}	route time to community j (in hours)
$B^{(j)}$	yearly number of visits to community j
$B_t^{(j)}$	average number of visits per tour in community j
C	truck collection capacity (in tons)
$M_v^{(j)}$	mass of oil per visit in community j (in tons)
d_{kj}	distance from collector k to community j (in km)
S_v	velocity of a truck (in km/hour)
$T_d^{(j)}$	time needed for an average distance in community j (in hours)
T_v	time to collect at a producer (in hours)
T_l	time to empty the truck (in hours)

2.1. SUPPLY OF WASTE OIL PER COMMUNITY

2.1.1. ASSUMPTIONS

(1) all garages in a community produce the same volume of waste oil,

(2) the volume of garage waste oil per community increases linearly with the number of cars subscribed in the community,

(3) all cars of all makes of a certain type drive the same distance in a year.

2.1.2. DATA DESCRIPTION

(1) v_i $(i \in In)$; data yearly reported by the producers to OVAM (Public Waste Office in Flanders)

(2) $n_g^{(j)}$; data available from FEGARBEL / VEGA (1986)

(3) $n_w^{(j)}$; data available from N.I.S. (The National Institute of Statistics) (1986)

(4) d_k; data available from FEGARBEL / VEGA (1986)

(5) r_{kl}; data available from an enquiry made by Byl (1987)

(6) o_{kl}; data available from an enquiry made by Byl (1987)

(7) n_{kl}; data available from N.I.S. (1986)

2.1.3. MODEL FORMULATION

With $I = I_n \cup I_g$

$$V^{(j)} = V_n^{(j)} + V_g^{(j)} = \sum_{i \in I_n} v_i \delta_{ij} + \sum_{i \in I_g} v_i \delta_{ij}$$

where $\delta_{ij} = \begin{cases} 1 & \text{if producer } i \text{ lives in community } j, \\ 0 & \text{else} \end{cases}$

The weight from producer i living in community j is

$$v_i = \sum_j v^{(j)} \delta_{ij} \qquad (i \in I_g)$$

where $v^{(j)} = V_g^{(j)} / n_g^{(j)}$ by assumption 1

$$V_g^{(j)} = \frac{n_w^{(j)}}{\sum_j n_w^{(j)}} \cdot V_g$$ by assumption 2

$$V_g = V_{gp} + V_{gg} + V_{ga} + V_{gt} + V_{gl}$$
$$= \sum_{k \in T} V_{gk}$$

$$V_{gk} = \sum_{l \in L_k} \frac{d_k}{r_{kl}} \cdot o_{kl} \cdot n_{kl} \qquad \text{by assumption 3}$$

2.2. Waste oil collection process

2.2.1. Assumptions

(1) the waste oil production rate is constant during the year,

(2) a route includes the collection of oil in one community only,

(3) each collector has enough collecting capacities for the whole province supply,

(4) a community is served by the collector situated at the shortest distance.

2.2.2. Data description

(1) C = 15 tons

(2) S_v = 35 km/hour

(3) d_{kj} = based on Lambert-coordinates, as used in the house waste collection study by S.C.K. (Research Center for Nuclear Energy) (1980)

(4) T_v = 15 minutes

(5) T_l = 50 minutes

(6) distances are calculated as bird's eye view distances. To correct for motorway distances a 30% correction is added.

2.2.3. Model formulation

The collection time for the whole province is the sum of the individual community collection times:

$$T_{cp} = \sum_j T_{cj}.$$

As it is assumed that in one route a truck serves the producers of one community, the collection time for community j is the time for one route times the number of routes per year to community j:

$$T_{cj} = R^{(j)} \cdot T_{rj}.$$

The number of routes $R^{(j)}$ can be found from the number of visits to producers in community j per year and the number of visits per tour:

$$R^{(j)} = B^{(j)} / B_t^{(j)}.$$

The number of visits per tour depends on the truck collection capacity and the average mass of oil per visit in community j:

$$B_t^{(j)} = C / M_v^{(j)}$$

where $M_v^{(j)} = V^{(j)} / B^{(j)}$.

To determine the number of visits we apply the following visiting policy:

- separate large from small producers. The threshold is taken to be 15 tons/year,
- for a large producer i of community j:

$$B_i^{(j)} = v_i / C$$

- for the set of small producers i of community j:

$$B_i^{(j)} = \begin{cases} \sum v_i/15 & \text{if } \sum v_i \geq 45, \\ 3 & \text{if } 10 \leq \sum v_i < 45, \\ 2 & \text{if } 5 \leq \sum v_i < 10, \\ 1 & \text{if } 0 < \sum v_i < 5. \end{cases}$$

This policy is chosen because with low masses in a community lead to a too high fixed cost to execute a collection route.

The time needed for a route to community j, T_{rj} is calculated by:

$$T_{rj} = 2 \cdot \frac{d_{kj}}{S_v} + 2 \cdot \left(B_t^{(j)} - 1\right) \cdot T_d^{(j)} + B_t^{(j)} \cdot T_v + T_l.$$

The first term of the right hand side is the time needed to travel from collector to the community and back.

The second term relates to the driving time within community j. It is assumed that the trucks drive immediately to one producer and travels from there to the other producers and back. The community is modeled as a disk, so that from the known community surfaces the ray R can be computed. Knowing that the surfaces of a ring with thickness dr equals $2\pi r\,dr$, the average distance from the center to a point or a disk with ray R is given by:

$$E(\text{distance}) = \frac{1}{\pi R^2}\int_0^R r^2 \cdot 2\,\pi\,dr = \frac{2}{3}R$$

From this T_{rj} can be computed.

The third term includes the filling of the truck at each collection point.

The fourth term includes the emptying of the truck after visiting a community and returning to its home place.

3. DISCUSSION

In this chapter we (1) present summarized results from the inquiry on oil renewals for vehicles, (2) give for one community an elaborated example of how the model works, (3) give the results of a simulation aiming to locate a collector in a 'best' place in the province.

The table below shows the number inscribed in the province of Antwerp in 1986 for five categories of vehicles: cars, trucks, autocars, farm tractors and special cars. For a number of makes in each category an estimate was made on the distance run between two oil renewals, on the quantity of waste oil released at each renewal.

Using estimates on the average distance run per year for each type of vehicles, Table 1.

Table 1. Types of vehicles

type of vehicle	average distance run per year (in km)
cars	12000
small trucks	40000
autocars	65000
big trucks	70000

and a percentage for private disposal, we are able to estimate the quantity to be collected. As no estimates are available on the yearly distance run for tractors and special cars, two renewals are assumed.

The ranges over all makes for distances and oil quantities per renewal are included in the Table 2.

Table 2. Total weight of oil to be collected

Type of vehicles	Number inscribed	Range of distance between two oil renewals (in km)	Range of quantity released oil per renewal (in litres)	Total weight of oil to be collected (in tons)
cars	556846	5000 - 11250	3 - 5.5	1124.9
sm. trucks	45858	5000 - 10000	5.5 - 11	569.0
autocars	1894	7500 - 20000	20 - 29	65.0
big trucks	6303	7000 - 15000	15 - 25	393.8
farm tract.	12746	- - -	24	184.7
spec. cars	5795	- - -	20	70.0
TOTAL	629442			2407.4

We now present how the calculations are done for an example community, in case of SCHOTEN. Schoten has 12500 vehicles inscribed, which means 1.99% of the province. So we estimate the amount of waste oil to be collected 47.8 tons.

In Schoten are 5 garages, each assumed producing 9.86 tons. Besides this quantity, 34.8 tons are reported to OVAM by 10 non-garage producers. One falls in the category of big producers (i.e. > 15 tons). The 14 smaller producers total an amount of 65.5 tons.

According to our policy in the model (because 65.5 > 45 tons), this means that an average of 65.5 / 15 = 4.37 routes/year are made to this group of producers. The yearly number of visits to the community follows from those of the small producers, 4.37 · 14 = 61.2 and of the big producer, 17.1 / 15 = 1.1, totaling 62.3 visits. With a total weight of 82.6 tons to be collected in Schoten, each visit collects an average 1.33 tons. In a route a collector fills its truck with 15 tons, averaging 15 / 1.33 = 11.3 visits per route. 62.3 visits per year at a rate of 11.3 visits per route, lead to 5.5 routes per year.

We now calculate the average time required for one route to Schoten. As Schoten is situated at a distance of 7.8 km from its nearest collector (i.e. in Antwerp) it takes 0.44 hours to drive from Antwerp to a producer in Schoten and back. With a surface of 29.58 square kilometers, a disk with the same surface would have a ray of 3.07 km. The average distance on a disk from the center is 2/3 th of the ray. Further a 30% is added for the difference between bind bird's eye view distance and road distance, leading to an average distance traveled in 0.076 hours.

The time of distance traveling within Schoten is 2 * 10.3 * 0.076 = 1.57 hours. The factor 2 represents the travel from the center and back. The factor 10.3 is one visit less than the filling process takes place, summing up to 2.71 hours. If now the emptying time (0.83 hours) is added; the total time for one route to Schoten is:

$$0.44 + 1.57 + 2.71 + 0.83 = 5.55 \text{ hours.}$$

The yearly collection time for Schoten is then 5.55 * 5.5 = 30.5 hours.

In this way the collection time for each of the communities of the province of Antwerp is calculated.

This sums up to 1142 hours per year. Assuming that an effective working day lasts for six hours at a rate of 220 working days per year, this means that 0.865 trucks are needed. This result is surprising, knowing that a number of collectors in the province are appointed, each having more than one truck.

We believe that out surprise is not the result of the estimation technique but of the lack of correct reporting from the producer's side.

With this uncertainty in mind, it is a nice exercise to locate the collector with his one truck in a community in such a way that the total yearly collection time is minimized. This is done by an exhaustive simulation: the collector is located in each of the communities and the collection time is recalculated. Some of the results are presented in Table 3.

Table 3. Results of simulation

Postcod.	Community	Yearly collection time	Number of trucks required
2000	Antwerpen	1236	0.936 minimum
2300	Turnhout	1723	1.305
2400	Mol	1890	1.432
2500	Lier	1363	1.033
2800	Mechelen	1467	1.118
2490	Balen	1962	1.486 maximum

We are convinced that the location of a collector is a multicriteria problem. We see that the minimal yearly collection time is obtained if the collector is located in Antwerp. The fact that this is situated in a city can be a major drawback on another criterion based on environment as public health variables.

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